TALVIVAARA SOTKAMO MINE – BIOLEACHING OF A POLYMETALLIC NICKEL ORE IN SUBARCTIC CLIMATE

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Abstract: The main activity of the Talvivaara Mining Company Plc. is the development and exploitation of the Talvivaara deposits in Sotkamo, Finland using bioheapleaching. The Talvivaara deposits comprise one of the largest known sulphide nickel resources in Europe with 1004 million tonnes of ore, sufficient to support anticipated production for a minimum of 45 years. The mine started in late 2008 and will have an annual nickel output of approximately 50,000 tons when it reaches full production. In addition, the mine will also produce zinc (approximately 90,000 tpa), copper (approximately 15,000 tpa) and cobalt (approximately 1,800 tpa) as by-products of the process. The viability of bioheapleaching technology for the extraction of nickel has been demonstrated in a large on-site pilot trial using Talvivaara ore. The three year pilot has shown that the leaching process also works well in the subarctic climatic conditions of Eastern Finland.

Keywords: bioheapleaching, nickel, zinc, copper, cobalt, Talvivaara

1. Introduction

The Talvivaara deposits are located in the southern part of the Kainuu belt in Eastern Finland. They comprise two different polymetallic orebodies, which are located approximately three kilometres apart. The deposits are outcropping and relatively easy to mine. The mineral resources have been classified by Australian JORC code with 0.07% Ni cut-off at 1004 million tons, containing 0.23% of nickel, 0.51% of zinc, 0.13% of copper and 0.02% of cobalt.

The black schist ore and the possible utilization of the deposits have been extensively studied for over 20 years. It was quickly apparent from the ore dressing tests that a usable nickel concentrate was not achievable due to the high graphite content of the ore. Chemical and biological leaching options had to be considered as potential options (RIEKKOLA-VANHANEN, 1999).

Talvivaara black schist ore contains pyrrhotite, pyrite, sphalerite, pentlandite, violarite, chalcopyrite and graphite. The main silica containing phases are quartz, mica, anorthite and microcline. In addition to nickel, zinc, copper and cobalt the ore contains about 0.3 % of manganese, 10 % of iron, 9 % of sulphur, 8 % of carbon and 50 % of SiO_2. The distribution of nickel in different sulphides is pentlandite 71 %, pyrrhotite 21 % and pyrite 8 %. The distribution of cobalt is pentlandite 11 %, pyrrhotite 26 % and pyrite 63 %. All copper is in chalcopyrite and zinc in sphalerite.

2. Production process

Overview. The mining method at Talvivaara is large scale open pit mining. Materials handling covers all physical ore processing steps from the primary crusher to the heaps. After one and one-half years of bioleaching on the primary pad, the leached ore will be reclaimed, conveyed and restacked onto the secondary heap pad. After secondary leaching, the barren ore will remain permanently in the secondary heaps. In the metals recovery process, the metals will be precipitated from the pregnant leaching solution (PLS) using hydrogen sulphide. The resulting products will be intermediates to be transported for further processing in refineries operated by the company's customers.

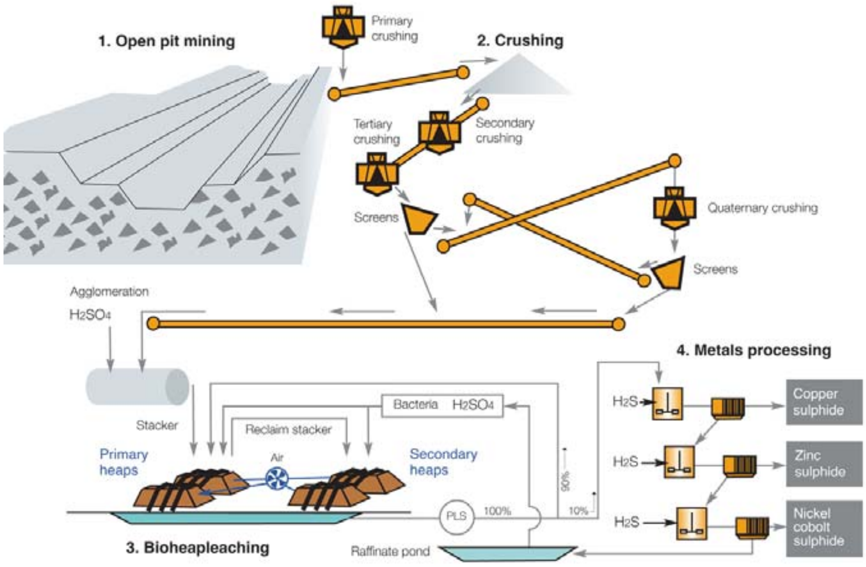

Fig. 1. Talvivaara process chart.

Open pit mining. Annual ore production is approximately 22 million tons. Sufficient areas to extend the pit will be prepared in subsequent years, normally a year prior to when mining is scheduled to commence. Any overburden or moraine not required for road, perimeter wall or other construction, will be stockpiled for later use in rehabilitation. Ore and waste are extracted using conventional large scale open pit drill and blast methods. A fleet of self-propelled diesel hydraulic track drill rigs are used. Fragmentation by blasting is preferred to crushing because of lower costs. It is also beneficial to create more fracturing at blasting stage, and it increases the surface area and therefore improves leaching solution entry and consequently leaching efficiency. As a result, the drilling pattern and hole sizes are on average smaller than in mines with similar production rates.

Materials handling and bioheapleaching. Materials handling in Talvivaara cover all the physical ore processing steps from the primary crusher to the final locations on the secondary heaps. During the process, the ore is crushed and screened in four stages. After primary crushing, the ore is conveyed to the following crushing stages and screening and is agglomerated for bioheapleaching. At this stage of leaching no inoculum from a bacteria farm is added. Agglomeration takes place in a rotating drum, where PLS is added to the ore in order to consolidate the fine ore particles with coarser ore particles. This preconditioning step makes the ore permeable to air and water for bioheapleaching. After agglomeration, the ore is conveyed and stacked eight meters high on the primary heap pad for one and one-half years of bioheapleaching. The heap pad is equipped with piping, laid on the bottom of the pad, through which low-pressure fans supply air to the stacked ore. From the top, the heap is irrigated with leaching solution, which is collected from the bottom of the heap. A ten percent side flow is taken for metals recovery and the rest of the solution is diluted with pure water in order to keep the amount of solution constant.

Fig. 2. PLS ponds, bioheap and metals plant

After one and one-half years of leaching on the primary pad, the leached ore is expected to be reclaimed, conveyed and restacked onto the secondary heap pad, where it will be leached further in order to recover metals from those parts of the primary heaps, where leaching solution has had poor contact. Such areas include, for example, the slopes of the heaps and areas between channels formed by the circulating leaching solution. At this stage the main part of copper and cobalt will be recovered, too. After secondary leaching, the barren ore is expected to remain permanently on the secondary heaps.

Metals recovery. In the metals recovery process, the metals are precipitated from the PLS using hydrogen sulphide. The resulting products are intermediates, such as copper and zinc sulphides and a mixed nickel cobalt sulphide. These intermediates are transported for further processing in refineries operated by Talvivaara's customers. The recovery process also produces gypsum as a secondary product which will be collected and remain in a separate pond on the mining site.

Water management. The water management plan for the Talvivaara Project area includes all relevant pipelines, ponds and pump stations related to the processes outside the metals recovery plant area. It also includes surface water management, effluent treatment and other surface water construction projects. Water management plays an important role at the operation. The most important component is the recycling of the leaching solution from the irrigation pond to the heap and thereafter to the PLS pond. From the PLS pond, approximately 90 per cent of the solution is recycled back to irrigation to increase the metal grade, while about 10 per cent is lead to metals recovery. After metals precipitation, the remaining solution goes into the raffinate pond to pH adjustment and is reused to irrigate the heaps.

Land and Infrastructure. Prior to construction of the pilot operation in 2005, the Talvivaara deposits had no existing mining facilities. The development of the infrastructure and services included:

- Access roads, internal roads and railway;
- Power supply;
- Fuel services;
- Drinking water supply/water management;
- Metal recovery facility and
- Sewage and waste management.

The first construction phase commenced in February 2007 with construction of roads to allow good access to the site and between the construction areas. The majority of all earthworks were completed by the end of 2008. The Talvivaara Sotkamo Mine operational area totals 61 km^2.

3. Bioheapleaching at Talvivaara

Bioleaching. Bioheapleaching has been chosen for the Talvivaara Sotkamo Mine based on its favourable capital and operational costs and the good performance data obtained with the technology in earlier trials with the Talvivaara ore. Talvivaara's application of the bioheapleaching technology has its origins at Outokumpu Research, where it has been developed in conjunction with Talvivaara ore since 1987. All the rights relating to the accumulated research and development data on bioheapleaching were transferred to Talvivaara in connection with the acquisition of the mining licenses in February 2004.

Talvivaara has developed bioheapleaching and metals recovery from leaching solutions in collaboration with Tampere, Helsinki and Lappeenranta Universities of Technology and OMG Kokkola Chemicals Ltd. The research and development work has been partly funded by the Finnish Funding Agency for Technology and Innovation, through capital loans and grants since early 2004. The company has also benefited from the European Union funded Bioshale Project. For example, GSF and Talvivaara set up, as part of the Bioshale project, a 110 tonne pilot trial in March 2005 to test bioheapleaching of Talvivaara ore. The trial was successfully started in -20ºC conditions, thus serving as an important indicator of the feasibility of the process in subarctic conditions prior to moving to larger scale on-site trials (RIEKKOLA-VANHANEN, 2005). Smaller scale laboratory trials have provided the company with an understanding of the key parameters of bioheapleaching e.g. particle size, pH value, temperature, oxidation and aeration rate.

The pH of the bulk solution is an important parameter in bioleaching processes. The acid pH range from 1.5 to 3 is normally considered to be non-selective against any specific iron- and sulphur-oxidizing acidophiles that may be potentially useful in biological leaching systems. The pH value used has to be chosen in a way to ensure maximum leaching of valuable metals but also to minimize the leaching of unwanted impurities from the ore. Dissolution of silicate has to be avoided, because it can create solution flow barriers by formation of amorphous, gelatinous precipitates (DOPSON *et al.*, 2008). At Talvivaara the pH value has to be kept over 1.5 in order to prevent silicate precipitation.

In order to validate the bioheapleaching process on a larger scale, a demonstration scale on-site pilot study was commenced at Talvivaara in May 2005 (RIEKKOLA-VANHANEN, 2007; PUHAKKA *et al.*, 2006). Heap irrigation was started in August 2005 and metals recovery in November 2005. The demonstration heap was constructed of 17,000 tons of Talvivaara ore. Similar to the laboratory scale trials, the company varied the key parameters to confirm the optimum conditions.

In laboratory tests the temperature remained at the room temperature level. The size of the demonstration plant was large enough to generate heat and the rise of temperature could be observed. The rise was due to the oxidation of the large quantity of pyrrhotite and pyrite in the ore. The temperatures measured inside the heap varied from 30°C to nearly 90°C. According to the measurements there were various temperature gradients inside the heap.

The heap was reclaimed during the coldest time in winter 2007 and moved to a new leaching pad. The temperature of the ore was 0 ^{0}C, when irrigation of the secondary heap was started at the end of February. The temperature started to rise immediately and was at the level of 80 ^{0}C in July and started to decrease gradually after that to the level of 20 – 40 ^{0}C, where it remained to the end of July 2008. At that time the pilot had to be stopped in order to start mining in that area.

The on-site pilot trial demonstrated that the leach solution temperature and temperatures inside the heaps are practically independent of the surrounding environmental conditions.

The oxidative leaching of sulphide minerals is associated with acid production (e.g. pyrite) or acid consumption (monosulphides) (AHONEN and TUOVINEN, 1994). Sulphide ores invariably contain accessory non-sulphide minerals some of which may be recalcitrant (e.g. quartz), or they may be susceptible to partial dissolution (e.g. micas, carbonate minerals) and may thereby influence the pH without the involvement of a redox reaction. Associated with these reactions are the acid-consuming oxidation of Fe^{2+} and the subsequent acid-producing hydrolysis of Fe^{3+}. Thus, the net acid consumption or acid production in bioleaching processes is the sum of several concurrent dissolution, precipitation, oxidation, and reduction reactions. The acid consumption of Talvivaara ore was 15 kg/t of ore in the primary leaching and 2 kg/t of ore in the secondary leaching.

Microbial community dynamics. The microbial inoculum to the pilot heap was obtained from local acidic metal-rich ponds that had developed naturally in areas adjacent to the exposed ore and which contain a wide range of different species of mineral oxidizing acidophiles. The enrichment was originally grown on elemental sulphur, ferrous iron and finely ground Talvivaara ore. In the final stage the culture was grown on elemental sulphur and ore dust in an aerated pond on site. The pH value was adjusted to 1.8 with sulphuric acid. The enrichment culture used for inoculation as revealed by PCR-DGGE-sequencing contained e.g. *Acidithiobacillus ferrooxidans*, *Acidithiobacillus caldus* and *Leptospirillum ferrooxidans.* Depending on the leaching conditions various chemolithotrophs became enriched during the progress of leaching. The moderate thermophiles *At. caldus* and *Sulfobacillus thermosulfidooxidans* were dominant during some periods of leaching. Also extreme thermophile archae were found (RIEKKOLA-VANHANEN, 2007).

These results demonstrate that the mine site waters and the ore harbour a microbial community consisting of several members and that depending on the leaching conditions and especially the leaching temperature the dominant biocatalysts become different. As the actual leaching heaps have gradients of temperatures due to the heat released in the exothermic reactions and the varying boreal conditions, succession of different organisms at different depths of the heap and at different times is obvious.

Leaching recoveries. The results from the demonstration plant were substantially better than anticipated based on laboratory and other pilot results and confirmed the viability of the bioheapleaching of the Talvivaara ore. It is assumed that most of nickel and zinc will be leached in the primary heap within one and one-half years. The leaching rates were calculated from the chemical analyses of the solution taken away for metal recovery. Every tenth sample was sent to an accredited laboratory in order to be sure that the results are correct.

The recovery rates were higher than anticipated. Nickel recovery reached 80 % within 400 days. The corresponding zinc recovery was 80 % in 480 days. The demonstration plant has shown that the assumed recoveries for nickel and zinc can be reached (PUHAKKA *et al.*, 2006).

The recovery of cobalt remained low and the leaching rate was progressing slowly over the first 500 days. Only 2.5 % of copper were recovered. Copper is in chalcopyrite. The main part of cobalt is in pyrite. As sulphide minerals have semiconductor properties, galvanic interactions appear when there is an electrical contact among mineralogical phases. During dissolution of a mineral assembly of different sulphides, those minerals that have the highest rest potentials behave as cathodes which mean that they are galvanically protected and their leaching is hindered until the minerals with lower rest potentials have been leached. The electrochemical potentials of chalcopyrite and pyrite are higher than the ones of pyrrhotite, pentlandite and sphalerite (RIEKKOLA-VANHANEN and HEIMALA, 1993). The leaching of copper and cobalt proceeded well in the secondary leaching phase of the demonstration plant.

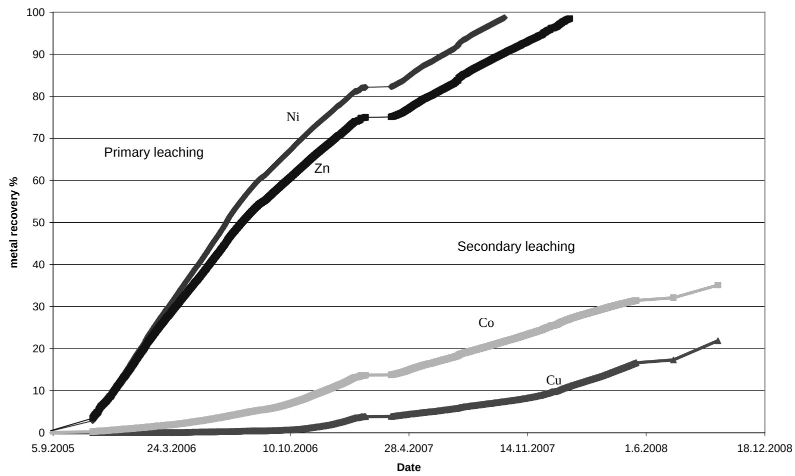

Fig. 3. Leaching recoveries in Talvivaara pilot.

4. Conclusions

Extensive research and pilot trials have proven bioleaching a feasible and environmentally sound technology in treating Talvivaara low grade sulphide nickel deposits in subarctic conditions. Talvivaara Project Ltd., which was established to build the mine and plant, progressed in the set timetable and budget. The mine and the plant are in industrial use since the beginning of year 2009.

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